The

Connecticut

Agricultural

Experiment

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New Haven

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Bulletin 1079

September 2021

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ABSTRACT
Ten cultivars of okra (*Abelmoschus esculentus* (L.) Moench) were evaluated at two sites in Connecticut for three years. The cultivars included Annie Oakley II, Clemson Spineless, Cow Horn, Emerald Green, Jambalaya, Lee, Millionaire, Red Burgundy, Silver Queen and Zarah. Yield, timing of harvest, and germination percentage were determined and other characteristics including plant structure, ease of picking, presence or absence of spines, and verticillium wilt disease susceptibility were noted. There were no differences in yields among seven of the ten cultivars. Jambalaya and Zarah appear to be good choices because of relatively high yields coupled with ease of picking and lower susceptibility to disease. Half of plants were grown utilizing black plastic mulch and half in bare soil production. For all three years, yields from the black plastic mulch plots were higher than yields from bare soil plots with yields increased up to 93% when summer temperatures were cooler. Plasticulture did not affect the timing of the yield. With an average increase in yield of 5,049 lbs/A (5,659 kg/ha) using plasticulture compared to bare soil production, the net profit increase more than offset the additional costs of supplies and labor.

INTRODUCTION

Okra is a tall-growing, warm season, annual plant from the same family as hollyhock, rose of Sharon, and hibiscus. The large flowers and upright plant (5 to 8 feet or more in height) have ornamental value for backyard gardens. Okra plants are extremely drought and heat resistant which make it a popular and important vegetable in countries with difficult growing conditions, especially tropical and subtropical parts of the world. The immature pod is utilized as a vegetable crop in the United States. Okra's leaves, seeds, and fiber are also important in other parts of the world (Lamont 1999). The fruit or pod, hairy at the base, is a tapering 10-angled capsule, 4-10 inches in length at maturity, that contains numerous oval, dark-colored seeds. The fruits are their most tender when they're 2-4 inches long. Pods reach this size within 4-6 days of flowering. As okra pods get larger, they become stringy and tough. However, with some cultivars, the pods remain tender and edible even when large. Important attributes of the pod are shape and color, as well as overall yield. As plants grow and bear until frost and the fruit must be picked frequently by hand, the extended fruit set period makes okra labor intensive. The plants of most cultivars are covered with small spines of hairs which are irritating to the skin making long sleeves and gloves necessary if harvesting more than a few plants. Because all okra is hand harvested, other cultivar attributes which make harvest easier such as petiole length, size of internodes, absence of spines on the leaves and pods and are important to consider. Today, over half of the okra acreage in the U.S. is grown in Texas, California, and Florida with another 23% grown in Alabama, Georgia, and South Carolina (USDA 2018). According to our survey, 35% of Connecticut's vegetable growers include okra at their farms.

Okra is a heat loving plant. It should be planted 3 to 4 weeks after the spring frost and not before night temperatures average above 50°F and the soil temperature is about 65°F. Temperatures higher than 68°F (20°C) are needed for normal development (Lamont 1999) and it grows best at temperatures between 75-90°F. In experiments with different mulches, Hill et al. (1982) found that there was an average soil temperature increase of 6°F using black plastic mulch compared to bare soil. Heat loving crops such as tomatoes and eggplant produced increased yields from plots amended with plastic mulch when compared to yields from the unamended controls. Decreased yields were observed on plots amended with organic mulches which cooled the soil. Plasticulture has the additional benefits of improved weed control and increased nutrient and water efficiency. Studies have shown the benefits of plasticulture in okra production in the southeastern United States (Maynard 1987). Khan et al. (1991) found that the use of plastic mulch, drip irrigation, and transplants can increase marketable yields in the southeastern U.S. by more than 3,000 lb/A (3,360 kg/ha) compared to bare ground. However, there is the added cost of supplies and labor in applying the plastic mulch. In Florida, Simonne et al. (2002) reported that plasticulture increased okra yields by 196 lb/A (220 kg/ha) per harvest and determined that it would take three harvests to offset the additional costs to plastic utilization. Preliminary studies in Connecticut indicated that okra yields were increased when black plastic was utilized but it was not been determined if the increase in yields were sufficient to offset plasticulture production costs (unpublished data). One-year trials were conducted with seven cultivars in Connecticut in 1998 on bare soil (Hill 2001), but many new cultivars have been developed since then. Mateus (2011) evaluated seven cultivars over two years in Massachusetts and found that okra can be commercially grown in Massachusetts with higher yields in hotter and drier growing seasons.

The objectives of this research were to (1) evaluate the field performance, plant characteristics, and yield of selected okra cultivars in production in Connecticut and (2) compare okra yields between plasticulture and bare soil production of okra in Connecticut. Both the cultivar and cultural findings should be of interest to growers in southern New England.

METHODS AND MATERIALS

Sites and soils. Okra trials were conducted over three years at the Valley Laboratory in Windsor CT on Merrimac sandy loam (Typic Dystrochrept), a sandy terrace soil with somewhat limited moisture holding capacity (Shearin and Hill, 1962); and at Lockwood Farm in Hamden CT on Cheshire fine sandy loam (Typic Dystrochrept), a loamy upland soil with moderate moisture holding capacity (Reynolds, 1979).

Cultivars. Ten okra cultivars were selected for their general availability, yield potential, and diversity in growth habit, pod shape, and color (Table 1). Seven cultivars (Clemson Spineless, Cow Horn, Emerald Green, Jambalya, Lee, Red Burgundy, and Silver Queen) were grown all three years. Because of seed availability, Millionaire and Annie Oakley II were grown the first two years and Zarah the last two years.

Culture. Each year, okra was seeded in a greenhouse on April 15-17. Seedlings were grown in Promix BX (Premier, Red Hill PA) in standard plastic pots (3601 insert) measuring 2 $^{5}/_{8}$ X 2 ¼ X 2 $^{5}/_{8}$ inches (volume 15.5 cubic inches) and placed in a greenhouse maintained at 75º-90ºF. After germination, plants were thinned to one per pot. Seedlings were moved to a cold frame for hardening before transplanting in the field. Water-soluble 20-20-20 fertilizer (one tbsp/gal) was added to the seedlings before they were transplanted in the field between May 25- June 5 at both sites. For the black plastic mulch experiment, rows 5 feet apart were covered with black plastic mulch (3' wide) applied by a tractor-pulled plastic-layer. Transplants were planted 1.5 feet apart in rows 5 feet apart (5,800 plants/A). Half of transplants were planted in holes punctured in black plastic mulch (3 feet wide) that was applied by a tractor-pulled plastic-layer. Drip irrigation tubing was laid as the plastic was applied. Half were planted in bare soil with drip irrigation tubing laid on top of the soil after planting. There were 15 plants per cultivar, with three blocks of five plants per cultivar.

Fertilization. Field soils (pH 6.5) were fertilized at a rate of 1300 lb/A (1,457 kg/ha) 10-10-10 just before transplanting. Different experimental fields at both locations were used each year to minimize potential disease build-up.

Weed Control. Weeds between plants in the bare soil experiment were controlled by hoeing and hand weeding. Weeds in the aisles of both experiments were mechanically controlled by rototilling.

Irrigation. Water was supplied by drip irrigation at both sites with all treatments. Plots were irrigated at both sites to ensure that plants received at least 1 inch of water per week either through rainfall or irrigation.

Insect and disease control. No insecticides, herbicides, or fungicides were necessary.

Harvest. Okra was harvested twice a week at both sites from the end of June to frost (end of October to the beginning of November) and the yield determined.

Germination test. For ten cultivars in 2016, thirty-six planting cells were seeded on April 15 with three seeds per cell for a total of 108 seeds. The number of germinated seeds was counted every week for three weeks.

Statistical Analysis. Comparison of yields (lbs per plant) were completed using SYSTAT 13.2 General Linear Model subroutine with cultivar, year, site (Windsor, Lockwood), and treatment (bare soil, black plastic) and their interactions using Type III sums-of-squares. While full models and subsets were examined, only parsimonious models with the lowest Akaike's Information Criterion (AICc) are presented (Burnham and Anderson 2002). Tukey's HSD test was used to test for significant differences among the cultivar yields at $p < 0.05$.

RESULTS AND DISCUSSION

Germination study. Four cultivars had germination percentages 85% and greater, with Annie Oakley II and Zarah averaging

94% (Table 2). The cultivar Lee had the lowest germination percentage (59%).

Pod yield. The average yields (lbs/A) of all cultivars over three years and two sites did not differ except Emerald Green had higher yields compared to Cow Horn, Lee, and Red Burgundy (Table 3). Annie Oakley II (only grown for 2 years) also had higher yields compared to Lee and Red Burgundy. In general, F1 hybrids performed better than open pollinated varieties with hybrids making up four of the top six varieties. When comparing yields in 2016, the only year when all ten cultivars were grown, the order of the cultivars from highest to lowest yields remained the same except for the cultivar Zarah which ranked ninth out of ten in 2016 compared with fifth when all the years are averaged. It appears that Zarah performed better compared to many cultivars in the poor yielding year 2017. Annie Oakley and Millionaire were not planted in 2017 when overall yields were lower compared to 2015 and 2016 (Table 4). Thus, the average yields of these cultivars may be artificially higher compared to the cultivars which were planted all three years.

Annie Oakley II performed well both in Florida and Connecticut (Simonne et al. 2002). While Emerald Green had the highest yields in Connecticut, while, Emerald Green yields in Florida were last or close to last in all trials. It appears Connecticut’s climate and soils are well-suited for cultivating Emerald Green, showing the importance of regional trials.

In all years, okra on plots amended with black plastic mulch produced higher yields compared to those on unamended bare soil plots (Table 4). The effect on yields of the black plastic mulch compared to bare soil was most pronounced in 2017, the year with the lowest overall yields. Yields on black plastic plots in 2017 were almost double (+93%) those on the unamended bare soil plots. Even in the other years when the overall yield was high, black plastic increased yields by 39-65%. Black plastic mulch warms the soil when compared to bare soil (Hill et al. 1982) and it appears that this increase is especially important for okra in cooler years. In addition, the cooler and wetter summer in 2015 led to more verticillium wilt disease (*Verticillium alboatrum* Reinke & Berthold) which adversely affected yields, especially in the bare soil plots. So not only were yields increased on the plastic amended plots from increased soil temperatures but yields from the bare soil plots were suppressed more than the plastic amended plots due to verticillium wilt disease. Similar decrease in yields in a cooler and wetter summer was also observed in Massachusetts (Mateus 2011).

The year 2017 was the coolest of the three years with the fewest accumulated growing degree days (GDD) at both sites during the key pod producing months of July, August, and September (Table 5). This was especially true in August, when most of the growth and development of okra pods in Connecticut occurs. GDD accumulation during August averaged 738 in 2015 and 2016 compared to 622 in 2017. In general, increased GDD accumulation resulted in greater yields; yields that were further increased with black plastic mulch. The year with the highest overall yields (2016) had the highest July and August GDD accumulation (Table 5). Yields in 2015 and 2016 on the bare soil plots were equivalent but yields from the plastic amended plots were higher in 2016 compared to 2015 (Table 4). It appears that the warmer temperatures in 2016 were accentuated by the plastic mulch which led to greater yields compared to 2015.

Does the plastic mulch affect the timing of the yield? The greatest percentage of the crop harvested by the end of August was in 2016 (Table 6) with an average of 61% of the crop harvested compared to 2015 and 2017 which averaged only 43 and 33% of the crop harvested by the end of August. Khan et al. (1990) and Lamont (1999) found that plastic mulch could increase earliness by as much as 21 days. However, in Connecticut, there was virtually no difference between plastic mulch and bare soil plots except in August of 2017 when a higher percentage (35%) of the crop from the unamended bare soil plots were harvested compared to the plastic amended plots (31%). By the end of September, 95-96% of the crop in both 2015 and 2016 had been harvested, whereas only 72-75% of the crop in 2017 had been harvested. In August 2017, a greater percentage of the crop had been harvested from the bare soil plots, while in September, a greater percentage of the crop was harvested from the plastic amended plots. It appears that the increase in soil temperature from the plastic amended plots had a greater effect in the cooler ambient temperatures of the fall which was also seen in the total yield (Table 4). The cooler temperatures throughout 2017 led to a longer harvest season with up to 28% of the total crop harvested in October and November (first hard frost did not occur until mid-November), compared to only 5% harvested in October and November in 2015 and 2016 (Table 6).

Cultivar considerations. To determine which cultivar to grow, there are other characteristics to consider in addition to yield (Table 7). Emerald Green (OP-open pollinated) had the highest yields compared to the other cultivars, but its germination percentage (66%) was poor (Table 7). Considering both seed germination and yield, Annie Oakley II (F1 hybrid) ranked first in germination compared to the other cultivars (94%) and second in yield averaging all years and in 2016. Zarah (F1) also had 94% germination but yields in 2016 ranked second to last compared to the other cultivars. Considering that all the yields were equivalent except for Cow Horn, Lee, and Red Burgundy relative to Emerald Green, and that Cow Horn and Lee had the lowest germination rates, other characteristics should also be considered. Emerald Green, Clemson Spineless, and Zarah had long internodes and long petioles with an open plant habit, making picking easy especially when compared to Annie Oakley II and Silver Queen whose pods are produced close to the stem on short petioles. However, Emerald Green was more susceptible to verticillium wilt compared to the other cultivars as was Annie Oakley II, Silver Queen, and Millionaire. The presence or absence of spines on the leaves and pods is an important characteristic. Taking all these factors into consideration, Jambalaya appears almost optimum with high germination and yield, average in ease of picking, and lower susceptible to verticillium wilt compared to the other cultivars. Zarah's open plant structure along with spineless leaves and pods make picking easier. The only negative of Jambalaya and Zarah is that they are hybrids which means the seeds are more expensive ($100/lb) compared to the open pollinated Emerald Green ($5/lb). This translates to $7/A for open pollinated varieties compared to $140/A for hybrids (Simonne et al. 2002). It should also be noted that Red Burgundy with its bright red pods could be considered a novelty crop and also planted as an ornamental.

Cost analysis of plasticulture. The additional costs for utilizing black plastic compared to bare soil production is the cost of the plastic mulch ($233/A or $94/ha) and the cost of plastic removal after the okra crop ($1528/A or $618/ha) (Table 8). Drip irrigation was used in both production systems and was laid at the same time as the plastic so plastic laying is not an additional cost in plasticulture production. The average increase in yield when using black plastic mulch was 5,049 lbs/A (5,659 kg/ha) (Table 4) so, with a retail price averaging $3.50/lb, the increased retail value when using black plastic was over $17,500/A which was well above the increased material and labor costs ($1,761/A). Even in 2015 when the difference in yields between plastic amended plots and bare soil plots was less (3,746 lbs/A), the increased retail value was $13,111/A which was still well above the added cost of plasticulture. Most okra grown in Connecticut are in plots much less than one acre, but the relative increase in profits are still the same. It should be noted that there are some additional costs when growing okra on bare soil not included in this analysis. These undocumented costs include increased labor for cultivation to control weeds in the rows and around the plants and/or from herbicide application. If these costs had been included, the increased profitability of plasticulture for okra production would have been greater relative to production in bare soil.

SUMMARY

Averaged all the years at both sites, yields of 7 of the 10 cultivars tested did not differ. Emerald Green and Annie Oakley II had the highest total marketable yields. Considering other characteristics that contribute to plant health and ease of picking, Jambalaya and Zarah also appear to be good options. Plasticulture increased yields up to 93% compared to bare soil production but had no effect on the timing of the yield. The effect of the black plastic mulch compared to bare soil was more accentuated when summer temperatures were cooler. Economical comparisons based on yields between plasticulture and bare soil production suggest that using plasticulture in okra production appear to lead to greater profits in Connecticut and is well worth the additional expenses.

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Table 1. Characteristics of evaluated okra cultivars grown in Hamden and Windsor CT in 2015, 2016, and 2017.

Annie Oakley II - F1 Hybrid - Short internodes, compact plants, pods spineless, long-tapered, uniform, slightly ribbed

Clemson Spineless - Open pollinated heirloom – Open, tall, vigorous plant with spineless leaves, bright green tapered spineless pods with long petioles making harvesting easier

Cow Horn – Open pollinated heirloom – Pods spineless, up to 14” long, best picked 6-10” long, remains tender even when long, susceptible to verticillium wilt

Emerald Green – Open pollinated heirloom – Tall plant, with smooth spineless pods 6-8” long, thin, dark green, thin, thick-walled, stays tender even when very large, long internodes making picking easy, developed in 1950 by the Campbell Soup Company

Jambalaya – F1 Hybrid – Early maturing plant, pods uniform shiny dark green 6-7” long

Lee– Open pollinated heirloom – Semi dwarf plant, pods dark green 6-7” long

Millionaire – F1 Hybrid – Early hybrid of Clemson spineless, susceptible to verticillium wilt disease

Red Burgundy – Open pollinated heirloom – Deep red colored pods and stems, green leaves, could be an ornamental, pods remain tender up to 8”

Silver Queen – Open pollinated heirloom – Whitish green pods, big leaves that remain healthy through October, pods close to the stem making them hard to pick, susceptible to verticillium wilt disease

Zarah – F1 Hybrid – Early, dark green glossy smooth pods with 5 distinct ridges, straight to slightly curved, open with large internodes, easy to pick

Table 2. Average germination (%) of okra in greenhouse one month after seeding in 2016.

Cultivar	Percent Germination
Annie Oakley II	94
Zarah	94
Jambalaya	89
Red Burgundy	85
Silver Queen	78
Millionaire	78
Clemson Spineless	68
Emerald Green	66
Cow Horn	64
Lee	59

Table 3. Average yield (# pods/plant) (lbs/plant) (lbs/A) of okra cultivars grown on bare soil or black plastic at Windsor and Hamden CT in 2015, 2016, and 2017 at a spacing of 5 X 1.5 feet or 5800 plants/A.

Cultivar	# pods/plant	lbs/plant	(lbs/A)***	2016 yields (lbs/A)__
Emerald Green OP	77	2.2	12,826 a	16,240
Annie Oakley II* F1	77	2.2	12,777 ab	15,776
Jambalaya F1	73	2.1	12,031 abc	15,213
Silver Queen OP	69	2.0	11,451 abc	14,947
Zarah** F1	67	1.9	11,153 abc	13,025
Millionaire* F1	66	1.9	10,904 abc	14,533
Clemson Spineless OP	64	1.8	10,656 abc	13,754
Cow Horn OP	61	1.7	10,042 bc	13,672
Lee OP	59	1.7	9,794 c	13,108
Red Burgundy OP	59	1.7	9,711 c	12,428

*Grown in 2015 and 2016 only
**Grown in 2016 and 2017 only
***Yields followed by the same letter not significantly different at P<0.05 using Tukey's HSD test

Table 4. Average yield (lbs/A) of okra grown on black plastic or bare soil in Windsor or Hamden CT in 2015, 2016, or 2017 at a spacing of 5x1.5 feet or 5800 plants/A.

Year	Treatment	Yield*
2015	Bare soil	9,727 c
2015	Black plastic	13,473 b
2016	Bare soil	10,755 c
2016	Black plastic	17,748 a
2017	Bare soil	4,739 d
2017	Black plastic	9,147 c

*Yields followed by the same letter not significantly different at P<0.05 using Tukey's HSD test

Table 5. Monthly accumulated Growing degree days (GDD) for July, August, and September in 2015, 2016, and 2017 at Hamden and Windsor, CT. GDD are based on 50ºF.

Month	Year	Windsor	Hamden
July	2015	723	719
	2016	772	759
	2017	688	684
August	2015	711	715
	2016	768	758
	2017	623	622
September	2015	540	530
	2016	514	518
	2017	486	499

Table 6. Percentage (%) of total okra crop harvested in August and September 2015, 2016, and 2017 from bare soil (s) plots and plots amended with black plastic (p).

	August			September		
Cultivar	2015	2016	2017	2015	2016	2017
Jambalaya (s)	43	53	40	97	94	80
Jambalaya (p)	39	59	37	95	96	83
Lee (s)	48	62	37	94	98	73
Lee (p)	44	59	32	96	96	79
Clemson (s)	42	66	35	96	99	78
Clemson (p)	49	65	30	96	97	74
Red Burgundy (s)	42	59	32	94	96	72
Red Burgundy (p)	50	62	33	99	95	77
Emerald Green (s)	34	57	34	92	93	69
Emerald Green (p)	38	58	23	96	95	69
Cow Horn (s)	46	60	36	96	95	70
Cow Horn (p)	40	60	30	97	95	72
Silver Queen (s)	41	58	34	93	93	62
Silver Queen (p)	43	63	30	95	96	71
Average (s)	43	61	35	95	95	72
Average (p)	43	61	31	96	96	75

Table 7. Comparison of yield (1-10, highest to lowest), germination (1-10 highest to lowest, plant openness, lack of spines, and susceptibility of verticillium wilt disease of evaluated okra cultivars

Cultivar	Yield Ranking Susceptibility	Germ. Ranking	Plant Openness*	Lack of Spines**	Disease***
Annie Oakley II	2	1	-	+	-
Clemson Spineless	7	7	+	+	+
Cow Horn	8	9	0	+	+
Emerald Green	1	8	+	+	-
Jambalaya	3	3	0	-	+
Lee	9	10	-	-	+
Millionaire	6	5	0	-	-
Red Burgundy	10	4	+	+	+
Silver Queen	4	5	-	-	-
Zarah	5	1	+	+	+

*plant openness - + long petioles and internodes (>2”), - short petioles and internodes (<1”), 0 neither long or short (1-2”)

**lack of spines - + no or little spines on leaves and pods, - pods and leaves spiny

***disease susceptibility - + plants not as susceptible to verticillium wilt disease, - plants relatively susceptible to verticillium wilt disease

Table 8. Extra cost of plasticulture in okra production in Connecticut.

1 roll of black plastic - $107/4000 feet – need 2.178 rolls for 1 acre (5 ft between rows) = $233
Labor hours of plastic removal (based on 1 acre) (adapted from Mateus 2011) – 69 hours x $12.00/hour = $828
Machinery hours of plastic removal (based on 1 acre) (adapted from Mateus 2011) – 35 x $20.00/hour = $700